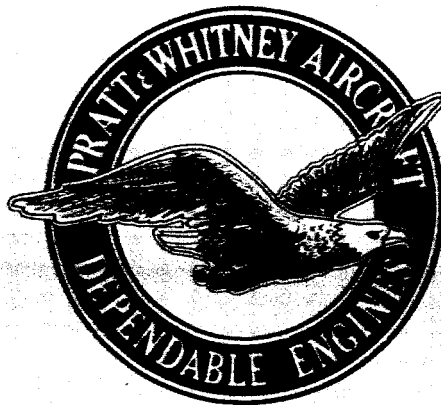


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**Pratt & Whitney Aircraft** DIVISION OF UNITED AIRCRAFT CORPORATION

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EAST HARTFORD 8, CONNECTICUT

Summary Report  
Beryllium Diffusion Barrier Coatings  
PWA-2184

Technical Management: National Aeronautics &  
Space Administration, Lewis Research Center,  
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## FOREWORD

This report describes the testing of coated beryllium samples carried out in fulfillment of Amendment 8 of contract NASw-104. It also describes environmental testing of beryllium oxide coatings carried out in a separate program.

## ABSTRACT

Beryllium strips were plasma-arc sprayed with chromium, iron, titanium and beryllium oxide. Additional strips were electroplated with gold. The coated strips were exposed to temperatures of 1400°F and pressures in the range of  $10^{-5}$  to  $10^{-7}$  mm Hg for periods of 150 and 500 hours. After exposure, all of the coated strips except those coated with beryllium oxide were analyzed by x-ray diffraction to determine the extent of diffusion.

Of the coatings exposed, only the beryllium oxide coatings remained intact for the duration of the exposure. The chromium and iron coatings separated completely, while the titanium coating spalled in localized areas. Interdiffusion between the gold coating and the beryllium substrate resulted in a brittle, highly blistered, nonadherent, unidentified phase.

## TABLE OF CONTENTS

	<u>Page</u>
Notice	ii
Foreword	iii
Abstract	iv
Table of Contents	v
List of Figures	vi
List of Tables	vii
I. Introduction	1
II. Procedure and Apparatus	2
A. Surface Preparation	2
B. Plasma-Arc Spraying	2
C. Electroplating	3
D. Vacuum Heating	3
III. Results	6
A. Visual Examination	6
B. X-Ray Examination	7
IV. Discussion of Results	8
A. Plasma-Arc Sprayed Coatings	8
B. Electroplated Coatings	9
V. Conclusions	10
VI. References	11
Appendix I - Tables	12
Appendix II - Figures	18

## LIST OF FIGURES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1.	Beryllium Strips Coated with Chromium and Iron. Coatings were Unsuccessfully Plasma Sprayed Using Nitrogen as the Carrier and Plasma Gas	19
2.	Beryllium Strips (As-Coated) Successfully Plasma Sprayed with Chromium, Iron, and Titanium Using Argon as the Carrier and Plasma Gas	20
3.	Beryllium Strips (As-Coated) with 1.0, 2.0 and 3.0-Mil Thick Plasma Sprayed Beryllium Oxide Coatings	21
4.	Beryllium Strips with 0.75 - Mil Thick Electroplated Gold Coating in the As-Coated Condition	22
5.	Beryllium Strips with 1.5 - Mil Thick Electroplated Gold Coating in the As-Coated Condition	23
6.	Heater Used for Barrier Coated Beryllium Tests	24
7.	Sample Holder with Specimens in Heater	25
8.	Sample Holder with Barrier Coated Beryllium Specimens	26
9.	Varian Vacuum Test Chamber Setup for Barrier Coated Beryllium Tests	27
10.	Elevated Temperature Exposure Data for Plasma Sprayed Chromium, Iron, and Titanium Coatings - 150 Hour Exposure	28
11.	Elevated Temperature Exposure Data for Plasma Sprayed Chromium, Iron, and Titanium - Completion of 500 Hour Exposure	29
12.	Elevated Temperature Exposure Data for Plasma-Arc Sprayed Beryllium Oxide Coatings - 150-Hour Exposure	30
13.	Elevated Temperature Exposure Data for Plasma-Arc Sprayed Beryllium Oxide Coatings - Completion of 500-Hour Exposure	31
14.	Elevated Temperature Exposure Data for Electroplated Gold Coatings - 150 Hour Exposure	32
15.	Elevated Temperature Exposure Data for Electroplated Gold Coatings - 500 Hour Exposure	33
16.	Beryllium Strips Plasma Sprayed with Chromium, Iron, and Titanium after 150 Hours of Exposure to 1400°F	34
17.	Beryllium Strips Plasma Sprayed with Chromium after 500 Hours of Exposure to 1400°F	35
18.	Beryllium Strips Plasma Sprayed with Iron after 500 Hours of Exposure to 1400°F	36
19.	Beryllium Strips Plasma Sprayed with Titanium after 500 Hours of Exposure to 1400°F	37
20.	Beryllium Strips Plasma-Arc Sprayed with Beryllium Oxide (1.0, 2.0, and 3.0 Mils Thick) after 150 Hours of Exposure to 1400°F	38
21.	Beryllium Strips Plasma-Arc Sprayed with Beryllium Oxide (1.0, 2.0, and 3.0 Mils Thick) after 500 Hours of Exposure to 1400°F	39
22.	Beryllium Strips Electroplated with a 0.75 - Mil Thick Gold Coating after 150 Hours of Exposure to 1400°F	40
23.	Beryllium Strips Electroplated with a 1.5 - Mil Thick Gold Coating after 150 Hours of Exposure to 1400°F	41
24.	Beryllium Strips Electroplated with a 1.5 - Mil Thick Gold Coating after 500 Hours of Exposure to 1400°F	42

## LIST OF TABLES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1.	Surface Cleaning Procedure for Plasma-Arc Sprayed Beryllium Strips	13
2.	Vapor Pressure of Exposed Materials at 1400°F	14
3.	Results of X-Ray Diffraction Analysis on Coated Beryllium Strips	15
4.	Thermal Expansion Coefficients of Exposed Materials at Elevated Temperatures	17

## I. INTRODUCTION

Beryllium is characterized by a high modulus of elasticity, lightweight, and high thermal conductivity. These properties make it a very desirable material for structural applications in space vehicles. In particular, beryllium appears to be a candidate material for thermal radiators in space vehicle powerplants using liquid metal coolants.

In the absence of an atmosphere, the thermal radiative properties of a material used for radiator construction become paramount. Metals, in general, have very low emittances. For example, beryllium has a thermal emittance of about 0.3 at temperatures being considered for space radiator operation. Except for efficiency considerations, for a given system the required radiating surface area varies inversely with the emittance. Therefore, an uncoated beryllium radiator would require a surface area about three times as large as a radiator coated with a material having an emittance of 0.9 for the same heat rejection rate.

Most materials with high emittances are oxygen-containing compounds. Beryllium, however, is very reactive chemically and at elevated temperatures may react with the coating to form beryllium oxide and, in some cases, complex beryllides. The result is an altering of the physical and chemical characteristics of the coating which make it useless as a space radiator.

An exploratory program was therefore undertaken to determine the feasibility of eliminating reactions between beryllium and a high-emittance coating by applying an intermediate coating by available techniques. The program evaluated the ability of the intermediate material to act as a diffusion barrier and substrate for a high-emittance coating and to retard weight-loss of the beryllium as a result of vaporization when exposed to a temperature of 1400°F and a pressure in the range of  $10^{-5}$  to  $10^{-7}$  mm Hg. For a material to fulfill these requirements it must be compatible with beryllium at elevated temperatures, that is, it must remain well bonded to the substrate and it must exhibit a low diffusion rate.

A number of promising materials were selected for investigation at a meeting between representatives of Pratt & Whitney Aircraft and NASA held at Lewis Research Center on June 11, 1962. A noble metal, gold, was chosen for its general inertness. An inspection of the phase diagrams of chromium, titanium, and iron indicated that these materials might also be suitable. Finally, beryllium oxide was selected as an example of a compound formed directly on the beryllium surface.

## II. PROCEDURE AND APPARATUS

### A. Surface Preparation

The coating-substrate bond strengths of coated materials are highly dependent on the surface condition of the substrate before the coating is applied. The surface must be rough and free from contamination if satisfactory bonding is to be achieved.

Beryllium strips were prepared for coatings of chromium, iron, and titanium at Pratt & Whitney Aircraft. Beryllium sheet 0.040 inch thick was cut into strips measuring approximately 1.5 x 2.0 inches. These strips were vapor degreased and pickled to produce a clean, roughened surface suitable for coating. The procedure and reagents used for this process are detailed in Table I.

Pratt & Whitney Aircraft contracted for additional strips to be prepared by Speedring Corporation, Warren, Michigan, for plasma-arc sprayed coatings of beryllium oxide and for electroplated coatings of gold.

### B. Plasma-Arc Spraying

1. Chromium, Iron, and Titanium Coatings - Initially, coatings of chromium, iron, and titanium were plasma-arc sprayed onto chemically cleaned beryllium strips. The chromium and iron powders used for spraying were supplied by the Fisher Scientific Company. Both were better than 99 per cent pure and had particle sizes between - 200 and + 325 mesh. The titanium powder was supplied by A.D. MacKay Incorporated. The powder was 99 per cent pure and had particle sizes smaller than -325 mesh. A standard plasma-arc spraying technique was used in which nitrogen was used as the carrier and plasma gas. The strip to be coated was clamped on a stand in the spray booth and the coating applied with manual control provided for the plasma gun. None of the coatings applied in this phase completely adhered to the substrate. It is believed that the powders reacted with the nitrogen before deposition on the workpiece. The appearance of the chromium- and iron-coated strips can be seen in Figure 1.

Subsequent work employed the same powders and spraying



technique but used argon as the carrier and plasma gas. The powder was fed to the carrier gas stream by a Silco powder feeder with vibrator. The workpiece-to-nozzle distance was maintained at about 2 inches throughout the operation and the automatic nozzle traverse was adjusted to provide a coating 2 to 3 mils thick. After coating, the strips were clamped between copper plates and cut into strips which measured about  $2.0 \times 0.5 \times 0.040$  inches. The cut was made from the coated side of the specimen using an abrasive cut-off wheel. The coatings applied by this method were generally satisfactory and are shown before sectioning in Figure 2.

During the spraying operation it was noticed that the particle size of the titanium powder was too small for proper powder feeding to the carrier gas with the equipment used. As a result, it was difficult to control the coating thickness.

2. Beryllium Oxide Coatings - Twenty-four beryllium strips measuring approximately  $2.0 \times 0.5 \times 0.040$  inches were plasma-arc sprayed on all surfaces with beryllium oxide by Speedring Corporation for Pratt & Whitney Aircraft. Eight of the strips had coatings 1.0 mil thick, eight had coatings 2.0 mils thick, and the remaining eight had coatings 3.0 mils thick. The appearance of the coated strips when they were received is shown in Figure 3.

#### C. Electroplating

Twelve beryllium strips measuring approximately  $2.0 \times 0.5 \times 0.040$  inches were electroplated with gold by Speedring Corporation. Pin contacts were used during the plating to provide a coating on all surfaces. Six strips had coatings 0.75 mil thick and the remaining six had coatings 1.5 mils thick. The appearance of these strips before testing is shown in Figures 4 and 5.

#### D. Vacuum Heating

1. General Procedure - The ultra-high vacuum system used was manufactured by Varian Associates. Pumping was accomplished by a 400 liter-per-second ion gettering pump and a mechanical roughing pump. Chamber pressure was measured both by the ion pump current and by a Bayard-Alpert type ionization gauge mounted on the vacuum chamber.

Heat for the strips was provided by a standard commercial calrod coil, the power to which was controlled by a Variac. A stainless steel shield completely enclosed the heating coil within the vacuum chamber to protect the chamber walls from metal vapor deposition and to aid in maintaining the temperature within the coil. See Figure 6. Temperature measurements were made by two chromel-alumel thermocouples; one located within the heating coil in the space above the specimens and the other inserted in the specimen mounting block. See Figures 6 and 7.

The coated strips were placed in slots machined in a stainless steel mounting block (Figure 8). The block containing the strips was placed horizontally in the coil, (Figures 6 and 7) and then the entire unit was placed in the vacuum chamber and sealed (Figure 9). Mechanical pumping reduced the chamber pressure to about  $10^{-3}$  mm Hg and then the ion-gettering pump reduced the pressure to  $10^{-7}$  to  $10^{-8}$  mm Hg. Power to the coil was adjusted to provide a heating rate which increased the temperature by about 200°F per hour until the temperature readings of both thermocouples reached 1400°F. The temperature was maintained as close as possible to 1400°F for the duration of the 150 - or 500-hour exposure. At the completion of the desired exposure time, power to the coil was shut off and the strips were allowed to cool under vacuum conditions until the ambient temperature was reached.

2. Plasma-Arc Sprayed Coatings - Three chromium, four iron, and three titanium coated strips were exposed during the initial heating cycle. At the completion of 150 hours at 1400°F the coil was withdrawn from the chamber and one chromium, two iron, and one titanium-coated strips were removed. These strips were visually examined, photographed, and then further examined using x-ray diffraction techniques. Data for this test appear in Figure 10. The remaining strips were returned to the chamber, heated to 1400°F, and exposed for an additional 350 hours to complete a 500-hour exposure. At this time they were removed and examined in the same manner as the strips exposed for 150 hours. Data for this test appear in Figure 11.

Twelve beryllium oxide-coated strips (four of each coating thickness) were exposed during a subsequent heating cycle. At the completion of 150 hours at 1400°F, two strips of each coating thickness were removed. Data for this test appear in Figure 12. The remaining strips were again heated to 1400°F and exposed for an additional 350 hours to complete a 500-hour exposure. Data for this cycle appear in Figure 13.

3. Electroplated Coatings - Two specimens with 0.75-mil thick gold coatings and two with 1.5-mil thick gold coatings were tested for 150 hours at 1400°F. Data for this test appear in Figure 14. Examination after 150 hours revealed that the 0.75-mil thick coatings would not remain adherent for 500 hours and therefore the specimens with 1.5-mil thick coatings were the only ones tested for 500 hours. Data for this test appear in Figure 15. After testing, the specimens were inspected by the same procedure used for the plasma-arc sprayed coated specimens.

### III. RESULTS

#### A. Visual Examination

After completion of each vacuum heating cycle, the strips were removed from the vacuum chamber and examined.

The chromium, iron, and titanium coatings spalled away from the substrate. The chromium and iron coatings displayed a satisfactory particle-particle bond with the coating layer remaining intact although separated from the substrate. The coating-substrate bond strength, however, was weak. Titanium, on the other hand, did not remain intact after separating from the substrate which indicates both a weak particle-particle bond and a weak coating-substrate bond.

Figure 16 shows the appearance of the chromium, iron, and titanium strips after a 150-hour exposure to a temperature of 1400°F and a pressure of about  $10^{-7}$  mm Hg. The chromium and iron coatings were intact but separated from the substrate. The condition of the remaining chromium and iron coatings is partially due to damage after removal from the heating chamber. In contrast, the titanium coating became granular and small particles spalled off in local areas.

Scale was found on the heating coil after 150 hours of testing which indicated vaporization of some of the coating. X-ray diffraction analysis indicated that the scale contained beryllium. At 1400°F the vapor pressure of beryllium is about  $5.2 \times 10^{-8}$  mm Hg (see Table II) and therefore some vaporization was expected.

The appearance of the chromium- and iron-coated strips which were exposed for 500 hours is shown in Figures 17 and 18. Comparison of Figures 16, 17, and 18 reveals that little change occurred during the second test run of these specimens and the comments made on the specimens exposed for 150 hours apply also to those exposed for 500 hours.

Figure 19 shows the appearance of the titanium-coated strips after a 500-hour exposure to 1400°F. It may be seen that the local areas of particle loss evident after 150 hours extended to cover almost the entire strip after 500 hours.

In contrast to the chromium, iron, and titanium coatings, the beryllium oxide coating remained completely adherent and sound after exposures to 1400°F for 150 and 500 hours. After exposure, examination revealed scattered pitting and a change in color from white to brown. No other changes were observed. The appearance of the beryllium oxide-coated specimens after exposure to 1400°F for 150 and 500 hours is shown in Figures 20 and 21 respectively.

The electroplated gold coatings displayed an appearance entirely different from those of the plasma-arc sprayed coatings. The 0.75-mil thick coating turned black, became brittle, and spalled away almost completely from the substrate (Figure 22). The 1.5-mil thick coating (Figure 23) became dark, brittle and had a blistered appearance but remained adherent to the substrate after 150 hours of exposure. Applying pressure to the blistered surface caused it to shatter and separate from the substrate in much the same manner as did the thinner coating exposed for the same duration.

The results of exposing the 1.5-mil thick gold coatings for 500 hours were much the same as those of the 0.75-mil thick coatings after 150 hours. The coating was discolored, severely blistered, and, for the most part, separated from the substrate (Figure 24).

#### B. X-ray Examination

With the exception of the beryllium oxide-coated strips, all of the strips were analyzed by x-ray diffraction after 150 and 500 hours of testing. In addition, some strips in the as-coated condition were analyzed for comparison purposes. Coatings which separated from their substrates were made into powder samples for analysis and their respective substrates were analyzed separately.

Results of x-ray diffraction analyses appear in Table III. Analysis employed standard General Electric x-ray diffraction equipment using chromium radiation except where noted in Table III.

#### IV. DISCUSSION OF RESULTS

##### A. Plasma-Arc Sprayed Coatings

Since the beryllium oxide coatings were the only plasma-arc sprayed coatings to remain adherent to their substrates, beryllium oxide is the only material of those which were plasma-arc sprayed which may still be considered suitable as a beryllium diffusion barrier.

Although no direct measurement of coating-substrate bond strength was made, a good indication of its quality is the appearance of the strips after elevated temperature exposure. The bond strengths of the beryllium oxide-coated specimens were clearly adequate to withstand the effects of the large (57 per cent) difference in coefficients of linear thermal expansion between the coating and the substrate. (Coefficients of linear thermal expansion of tested materials appear in Table IV.) The complete separation of the chromium and iron coatings, however, indicates an inadequate coating-substrate bond strength. The fact that the coatings remained intact after separating from the substrate indicates that the particle-particle bond strength was greater than the coating-substrate bond strength and that separation occurred during heating. The linear thermal expansion of beryllium is greater than that of chromium and iron by approximately 46 and 17 per cent respectively.

Results from x-ray diffraction analysis (Table III) show that no beryllium was detected in the chromium and iron coatings exposed for 150 and 500 hours. This indicates that these two coating materials separated before a substantial amount of interdiffusion occurred.

Analysis of the titanium-coated strips before testing revealed the presence of both  $Ti_2O$  and Be. The detection of Be indicates that the coating did not completely cover the substrate and allowed the beryllium to be exposed to the x-ray beam. The detection of  $Ti_2O$  indicates that the titanium partially oxidized during the spraying operation.

Analysis of the titanium-coated strips after 150 hours of testing again indicated that both  $Ti_2O$  and Be were present. Further, the bond between the coating and the substrate had almost completely failed so that particles of the coating material would separate from the beryllium even with the most careful handling.

In contrast to the results of x-ray diffraction analysis after 150 hours of testing, analysis after 500 hours did not detect any  $Ti_2O$ . This

result may be attributed to the nearly complete loss of the coating prior to analysis (see Figure 19).

#### B. Electroplated Coatings

As shown in Figure 22, the 0.75-mil thick electroplated gold coating separated from the substrate after 150 hours at 1400°F. The thicker (1.5-mil) electroplated gold coatings (Figure 23) were adherent to the substrates but had a blistered surface after the same exposure period. After a total of 500 hours of testing, the 1.5-mil thick coatings had appearances similar to those of the 0.75-mil thick coatings after 150 hours. In both instances, the photographs show that the 0.75-mil and 1.5-mil thick electroplated gold coatings were brittle at room temperature and separated from their substrates after exposures of 150 hours and 500 hours respectively.

Table IV indicates a very small difference in the thermal expansion coefficients of gold and beryllium (about 4.1 per cent). At 1400°F the coating was in slight tension and remained in intimate contact with the substrate, allowing interdiffusion of the substrate and coating to occur.

The constitution diagram in Hansen<sup>1</sup> of the gold-beryllium system indicates that compounds with compositions containing over 0.9 per cent Be by weight would have melting points in the 1070°F to 1330°F range. If interdiffusion of the coating and substrate did occur, at 1400°F a liquid interface would be formed when the beryllium concentration in the gold exceeded 0.9 per cent. As the concentration continued to increase, any of the numerous phases indicated by the constitution diagram could form during cooling.

X-ray diffraction analysis (Table III) indicates diffusion did occur since the coating and substrate contained an unidentifiable  $Au_xBe_y$  phase. This phase was found to be other than  $Au_2Be$ ,  $Au_3Be$ ,  $AuBe_5$  or  $AuBe$ . Hansen lists one other phase,  $AuBe_3$ , which is stable at room temperature and which may have been the phase present although this has not been confirmed.

The results of fluorescence patterns of this unidentified compound indicated only the presence of gold. It can therefore be assumed that the phase contains gold combined with an element or elements having an atomic number of 12 or smaller. (The atomic number of beryllium is 4.)

## V. CONCLUSIONS

The ability of the chromium, iron, and titanium coatings to act as diffusion barriers for coated beryllium could not be thoroughly evaluated because the coatings separated from the substrates. It is apparent, however, that plasma-arc sprayed coatings of these materials do not have adequate coating-substrate bond strength for the intended application.

The coatings of beryllium oxide, however, remained adherent and reasonably sound after 150- and 500-hour exposures to 1400°F. Further investigations would be required to determine whether or not beryllium oxide will act as a suitable diffusion barrier and substrate for high-emittance coatings.

The electroplated gold coatings apparently remained sufficiently adherent to the substrate to permit interdiffusion to occur. As the diffusion progressed, the beryllium concentration in the coating increased to the point where an unidentified phase was formed. The resulting phase appeared very brittle when examined at room temperature. Coupled with this were the relative ease of separation of the resulting coating from the substrate and a highly blistered appearance. The electroplated gold coating, as evaluated in this program, would therefore not be considered either as a suitable substrate for high-emittance coatings or as an effective diffusion barrier.



## VI. REFERENCES

1. Max Hansen, "Constitution of Binary Alloys," McGraw Hill Book Company, Incorporated, 1958, p. 187
2. C.J. Smithells, "Metals Reference Book," Third Edition, Butterworths, Incorporated, Washington, D.C., 1962, p. 655-656, 695-697
3. W.D. White Jr., J.E. Burke, Editors, "The Metal Beryllium," American Society for Metals, 1955, p. 308

APPENDIX I  
Tables

TABLE I

Surface Cleaning Procedure for Plasma-Arc  
Sprayed Beryllium Strips

## A. Pickle Solution Composition:

H<sub>3</sub>PO<sub>4</sub> - 450 ml per liter  
H<sub>2</sub>SO<sub>4</sub> - 26.5 ml per liter  
CrO<sub>3</sub> - 53 gm per liter

## B. Pickle Solution Temperature: 140°F

## C. Cleaning Procedure:

1. Agitate strips in heated pickle solution for 3 to 5 minutes
2. Rinse in cold water
3. Rinse in hot (150°F) water
4. Air dry

TABLE II  
Vapor Pressure of Exposed Materials  
at 1400°F<sup>2</sup>

<u>Material</u>	<u>Vapor Pressure (mm Hg)</u>
Beryllium	$5.2 \times 10^{-8}$
Beryllium Oxide	$2.2 \times 10^{-21}$
Chromium	$3.4 \times 10^{-10}$
Gold	$3.5 \times 10^{-10}$
Iron	$1.1 \times 10^{-10}$
Titanium	$8.4 \times 10^{-14}$

TABLE III

Results of X-ray Diffraction Analysis on  
Coated Beryllium Strips

<u>Coating Material</u>	<u>Hours of Exposure to 1400°F</u>	<u>Surface Analyzed</u>	<u>Phases Present</u>
Uncoated	0	Substrate	Be + BeO
Chromium	0	Coating	Cr
Chromium	150	Substrate	Be + BeO
		Coating	Cr
Chromium	150	Substrate	Be + BeO
		Coating	Cr
Chromium	500	Substrate	Be + BeO
		Coating	Cr
Chromium	500	Substrate	Be + BeO
		Coating	Cr
Iron	0	Coating	$\alpha$ Fe + FeO
Iron	150	Substrate	Be + BeO
		Coating	$\alpha$ Fe + FeO
Iron	500	Substrate	Be + BeO
		Coating	$\alpha$ Fe + FeO
Iron	500	Substrate	Be + BeO
		Coating	$\alpha$ Fe + FeO
Titanium	0	Coating	Ti <sub>2</sub> O <sup>(a)</sup> + Be

TABLE III (Cont'd.)

<u>Coating Material</u>	<u>Hours of Exposure to 1400°F</u>	<u>Surface Analyzed</u>	<u>Phases Present</u>
Titanium	150	Coating (b)	Ti <sub>2</sub> O + Be
Titanium	500	Substrate (c)	Be + BeO
Gold(0.75-Mil)	0	Coating	Au
Gold(0.75-Mil)	150	Substrate	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
		Coating	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
Gold(0.75-Mil)	150	Substrate	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
		Coating	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
Gold(1.5-Mil)	0	Coating	Au
Gold(1.5-Mil)	150	Coating (a)	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup> + AuBe <sub>5</sub>
Gold(1.5-Mil)	500	Substrate	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
		Coating	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
Gold(1.5-Mil)	500	Substrate	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>
		Coating	Au <sub>x</sub> Be <sub>y</sub> <sup>(d)</sup>

(a) Referenced in ASTM Card File, Andersson et al.

(b) Coating adhered to substrate

(c) Insufficient coating remained for powder sample

(d) Appeared identical in all strips examined. Not specifically identified but found to be other than AuBe, AuBe<sub>5</sub>, Au<sub>2</sub>Be or Au<sub>3</sub>Be.

TABLE IV

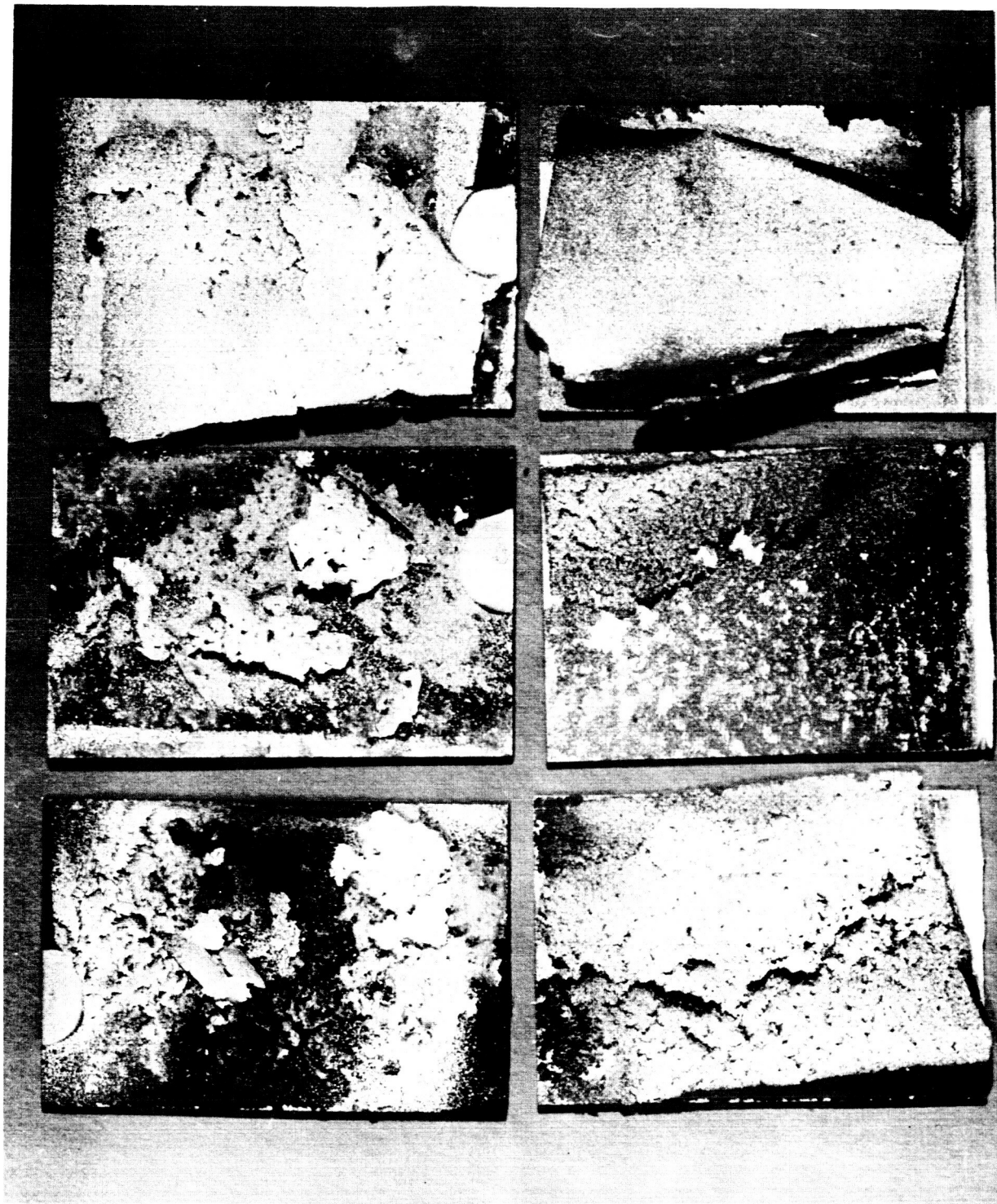
Thermal Expansion Coefficients of  
Exposed Materials at Elevated Temperatures

<u>Material</u>	<u>Temperature Range (°F)</u>	<u>Linear Coefficient of Expansion (in/in/°F)</u>
Beryllium <sup>3</sup>	77-1472	$9.7 \times 10^6$
Beryllium Oxide <sup>2</sup>	77-1472	$4.2 \times 10^6$
Chromium <sup>2</sup>	68-1292	$5.2 \times 10^6$
Gold <sup>2</sup>	68-1652	$9.3 \times 10^6$
Iron <sup>2</sup>	68-1112	$8.1 \times 10^6$
Titanium <sup>2</sup>	68-1472	$5.5 \times 10^6$

APPENDIX II

Figures

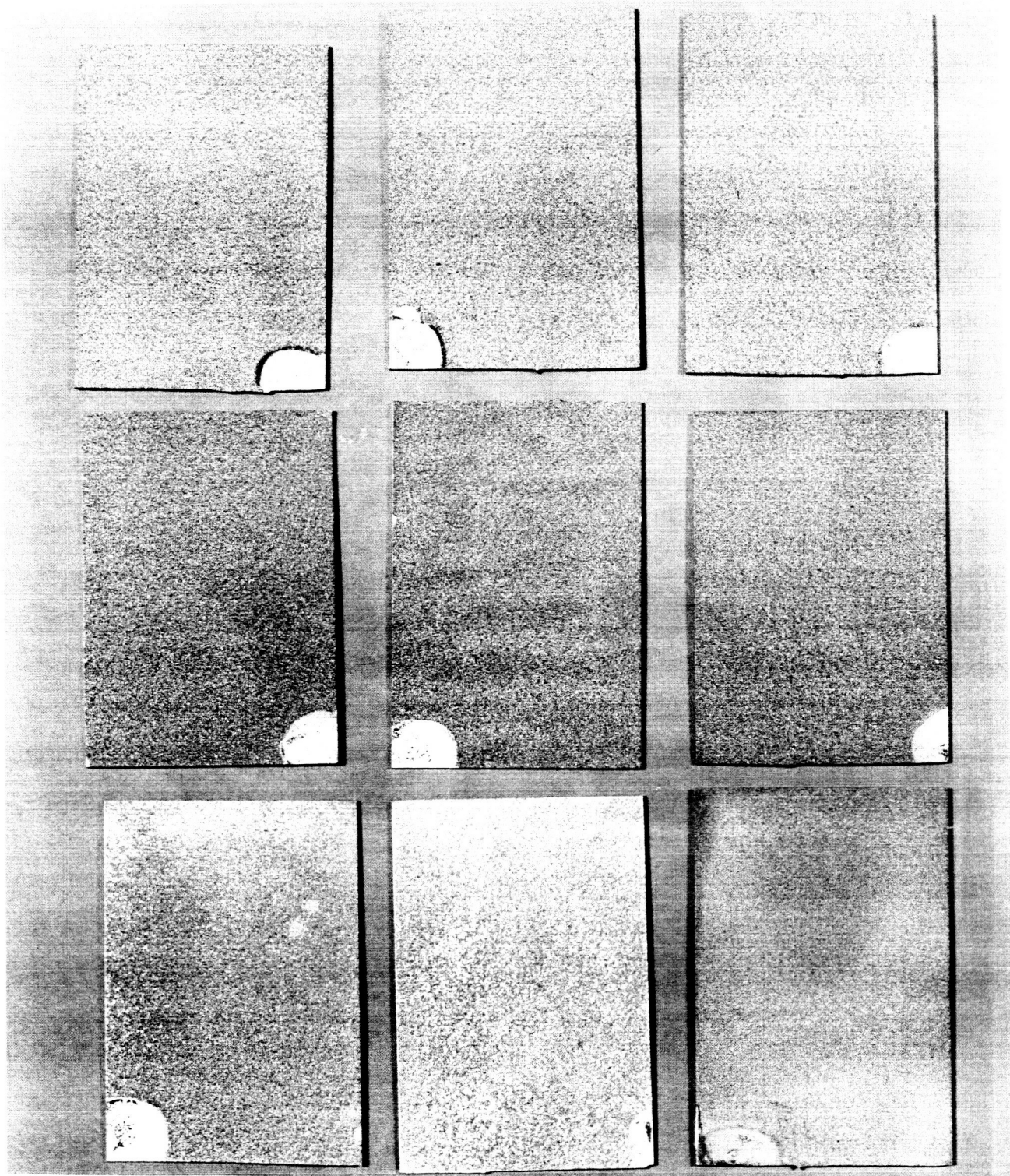




BERYLLIUM STRIPS COATED WITH CHROMIUM (TOP) AND IRON (BOTTOM).  
COATINGS WERE UNSUCCESSFULLY PLASMA SPRAYED USING NITROGEN AS  
THE CARRIER AND PLASMA GAS

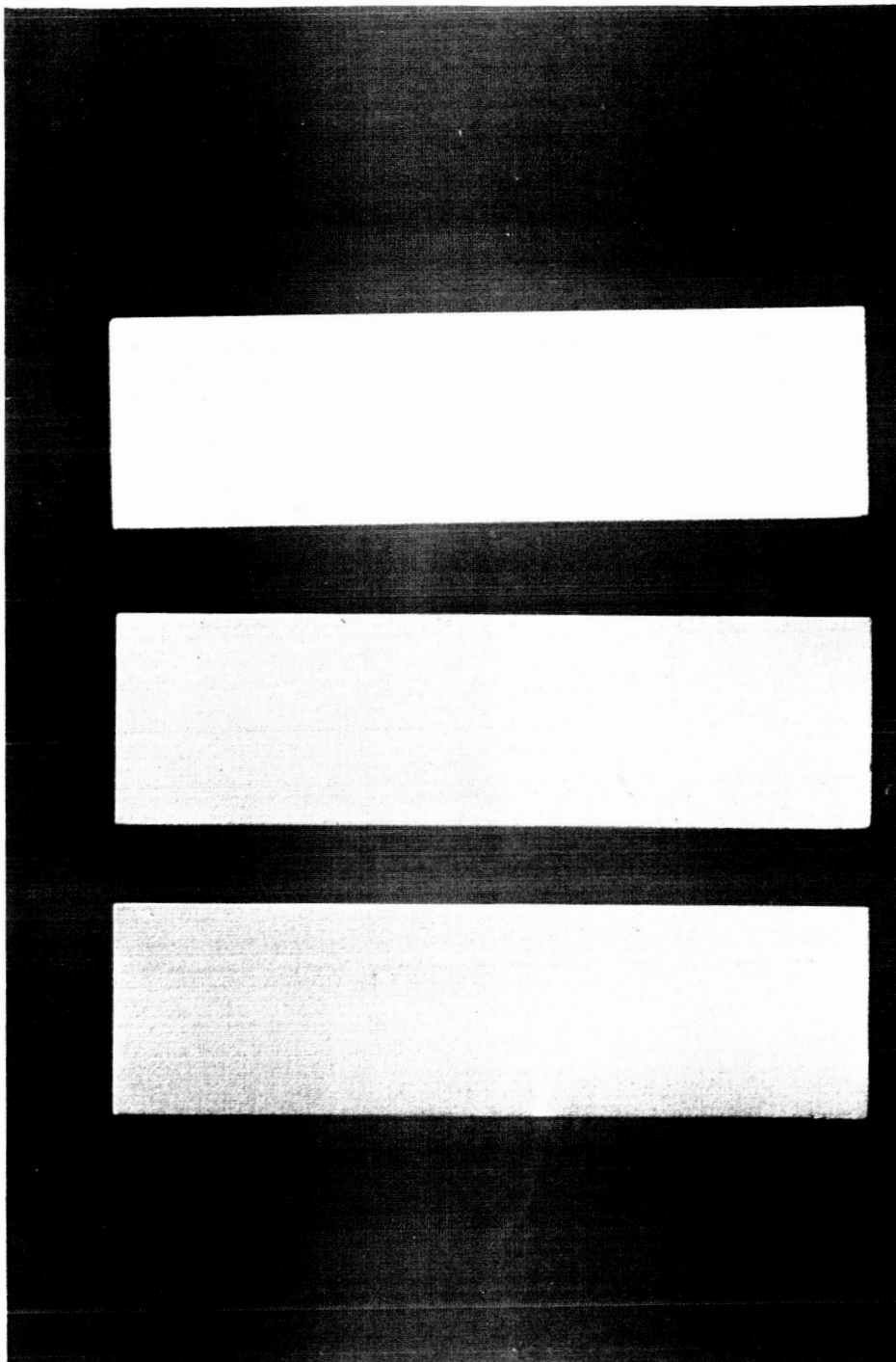


Figure 1



BERYLLIUM STRIPS (AS COATED) SUCCESSFULLY PLASMA SPRAYED  
WITH CHROMIUM, IRON, AND TITANIUM USING ARGON AS THE CARRIER  
AND PLASMA GAS

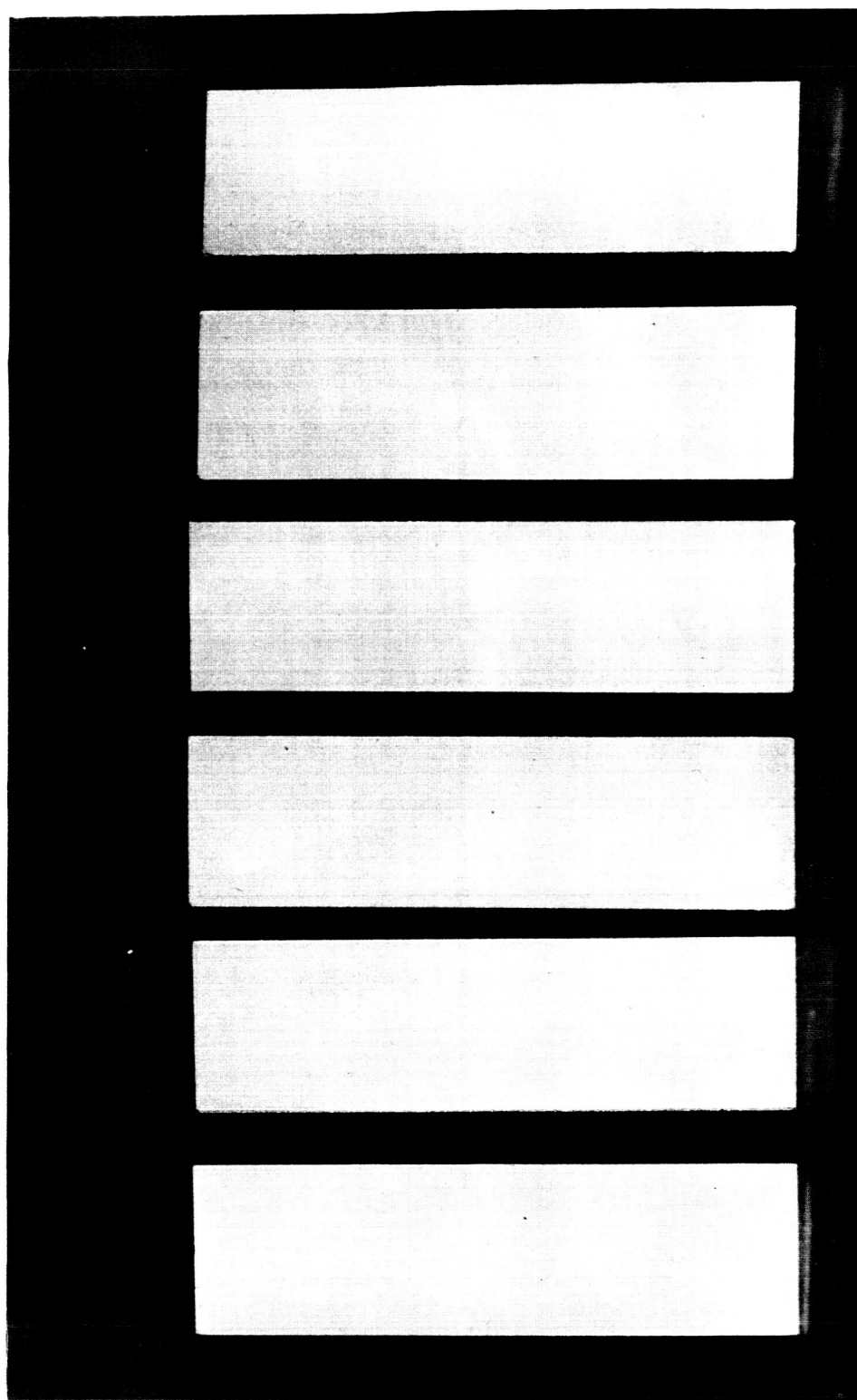
Figure 2



BERYLLIUM STRIPS (AS COATED) WITH 1.0, 2.0, AND 3.0-  
MIL THICK PLASMA-ARC SPRAYED BERYLLIUM OXIDE COATINGS



Figure 3

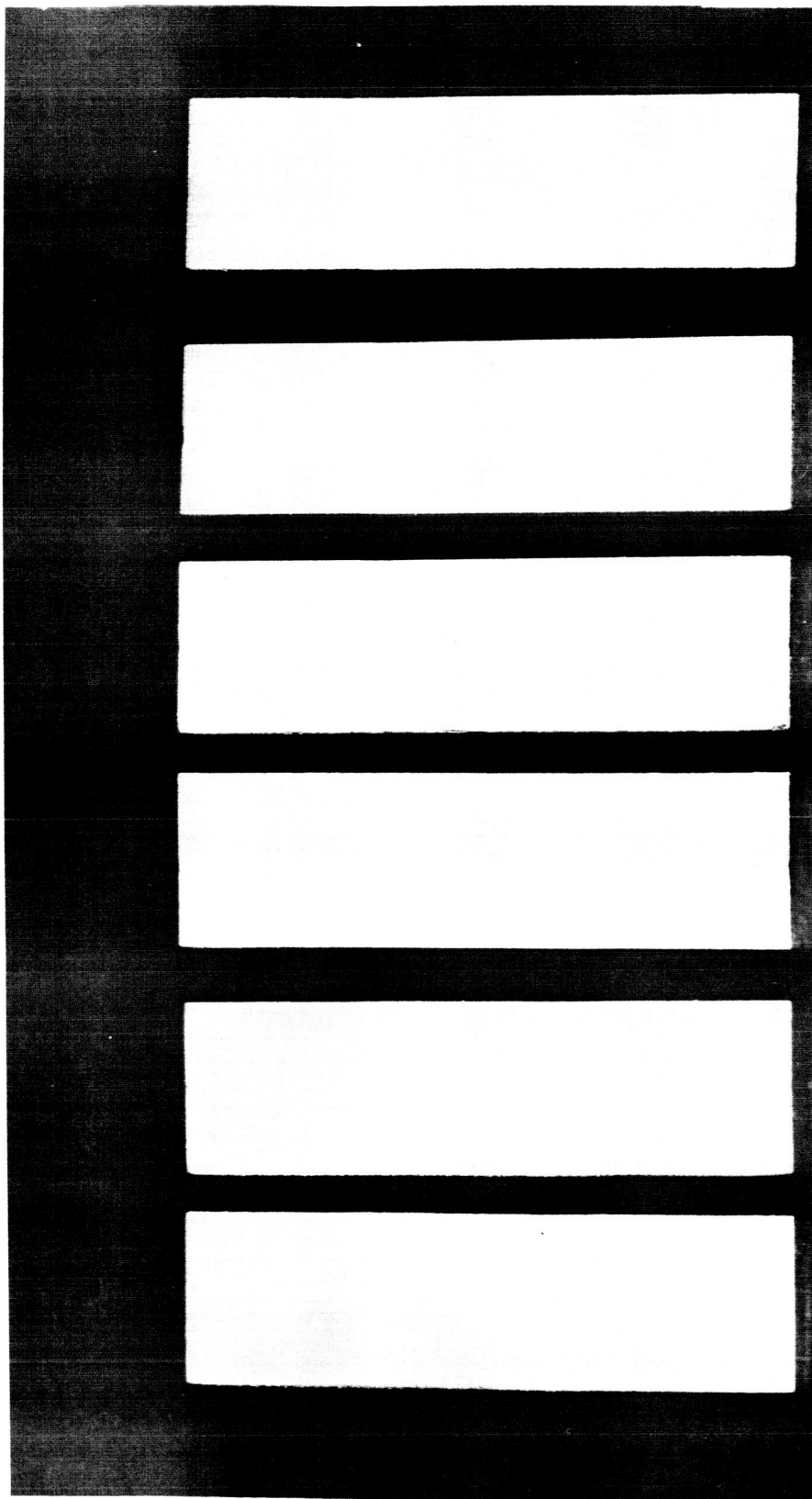


BERYLLIUM STRIPS WITH .75-MIL THICK ELECTROPLATED GOLD COATING  
IN THE AS-COATED CONDITION



Figure 4

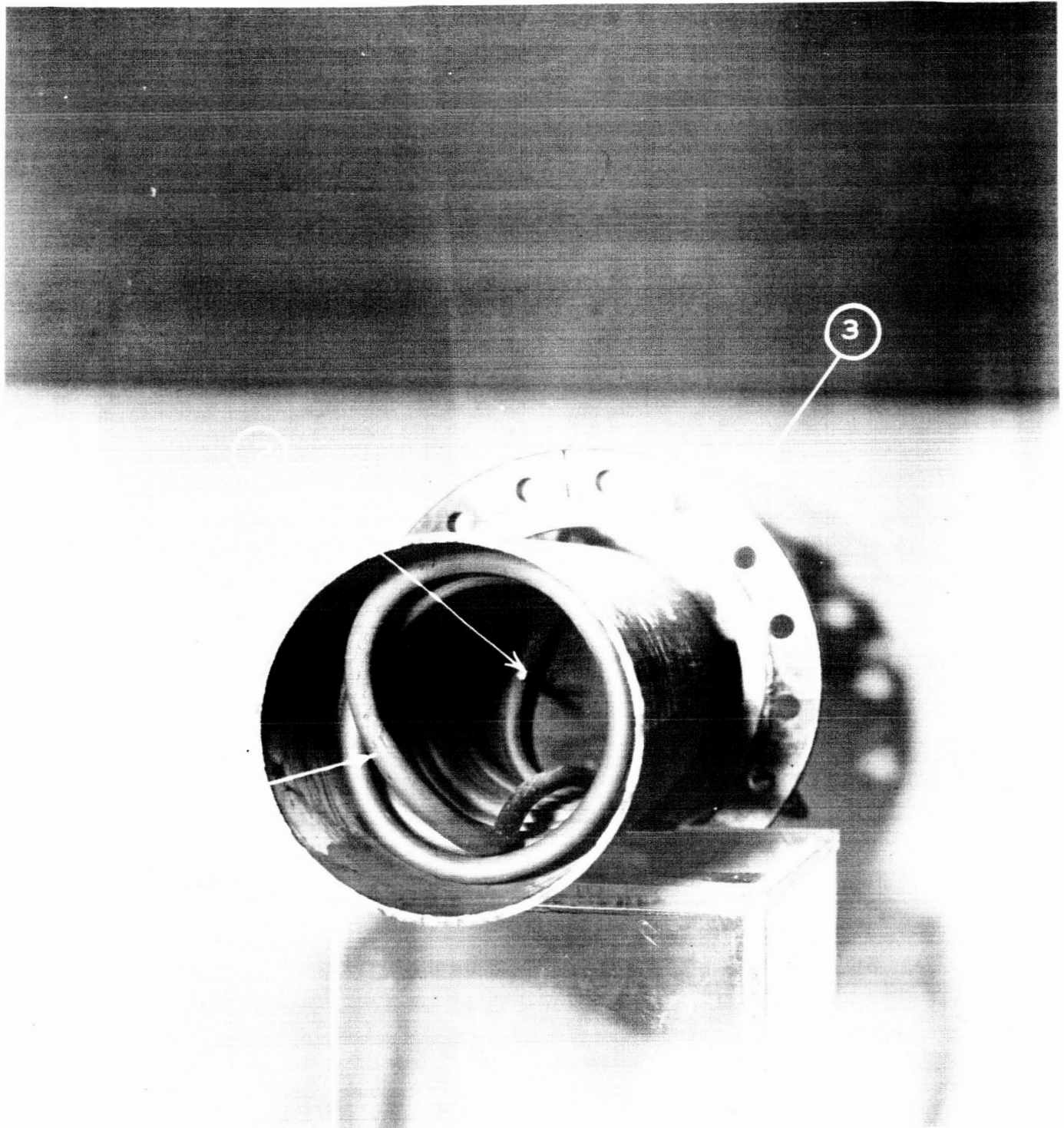




BERYLLIUM STRIPS WITH 1.5-MIL THICK ELECTROPLATED GOLD  
COATING IN THE AS-COATED CONDITION

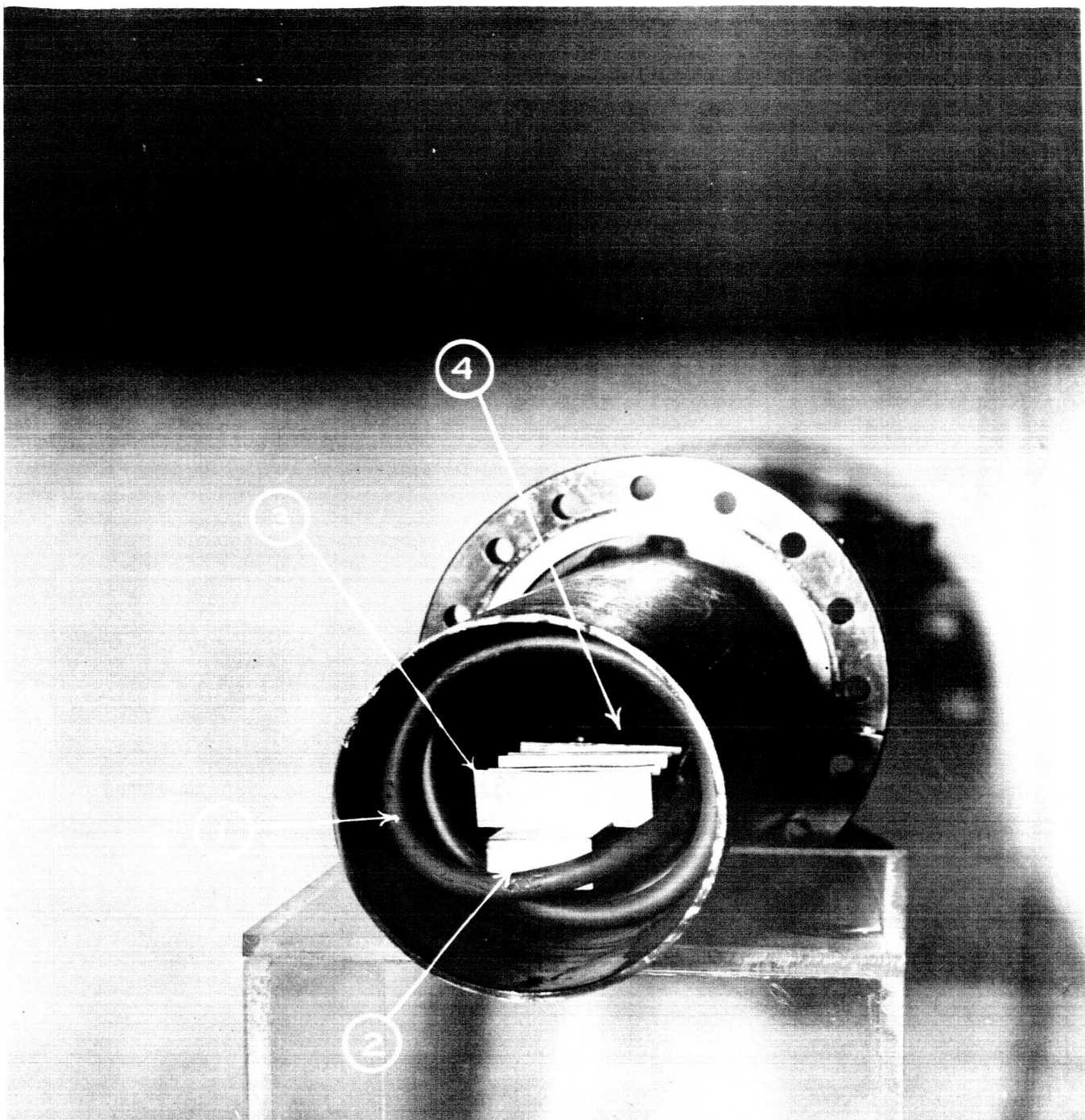


Figure 5



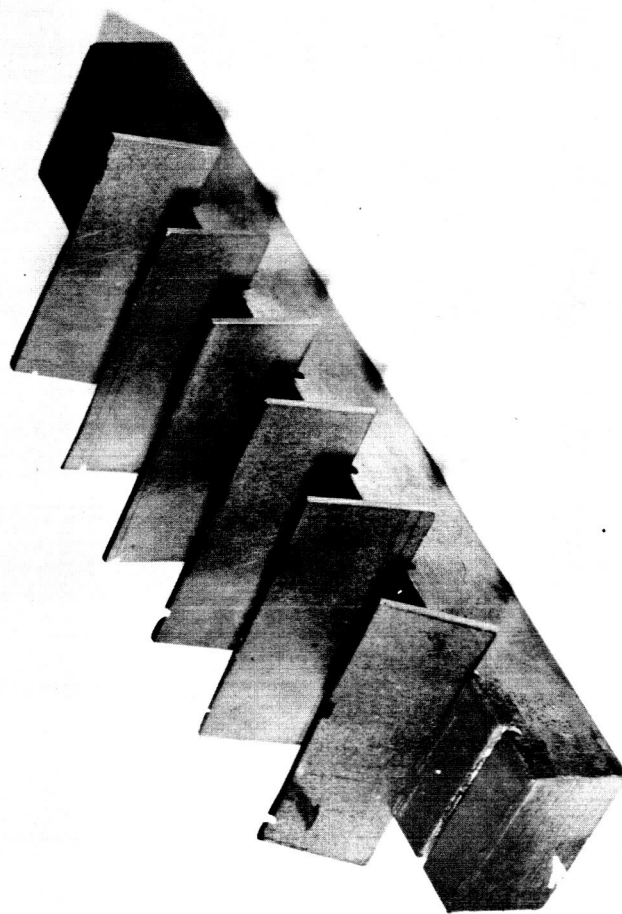
HEATER USED FOR BARRIER COATED BERYLLIUM TESTS  
 1- CALROD HEATER                      2- CHROMEL-ALUMEL THERMOCOUPLE  
 3- VACUUM CHAMBER PORT

Figure 6



SAMPLE HOLDER WITH SPECIMENS IN HEATER  
 1- CALROD HEATER  
 2- SAMPLe HOLDER  
 3- TEST SPECIMEN  
 4- THERMOCOUPLE

Figure 7

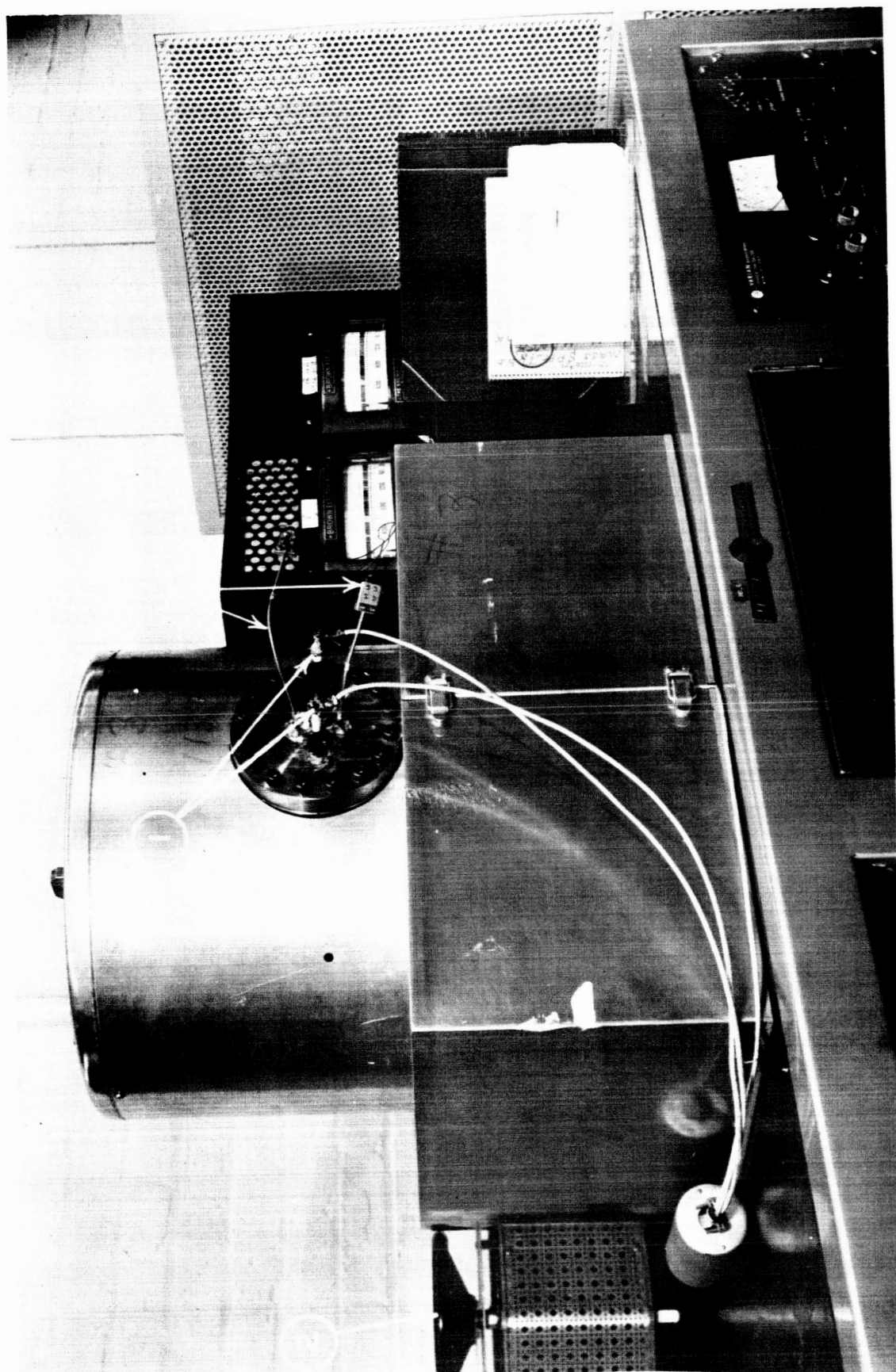


SAMPLE HOLDER WITH BARRIER COATED BERYLLIUM SPECIMENS  
1- STAINLESS STEEL HOLDER 2- TEST SPECIMENS



Figure 8





VARIAN VACUUM TEST CHAMBER SET-UP FOR BARRIER COATED  
BERYLLIUM TESTS  
1- CALROD CONNECTIONS      2- VARIAC      3- THERMOCOUPLES



Figure 9

# ELEVATED TEMPERATURE EXPOSURE DATA FOR PLASMA SPRAYED CHROMIUM, IRON, AND TITANIUM COATINGS

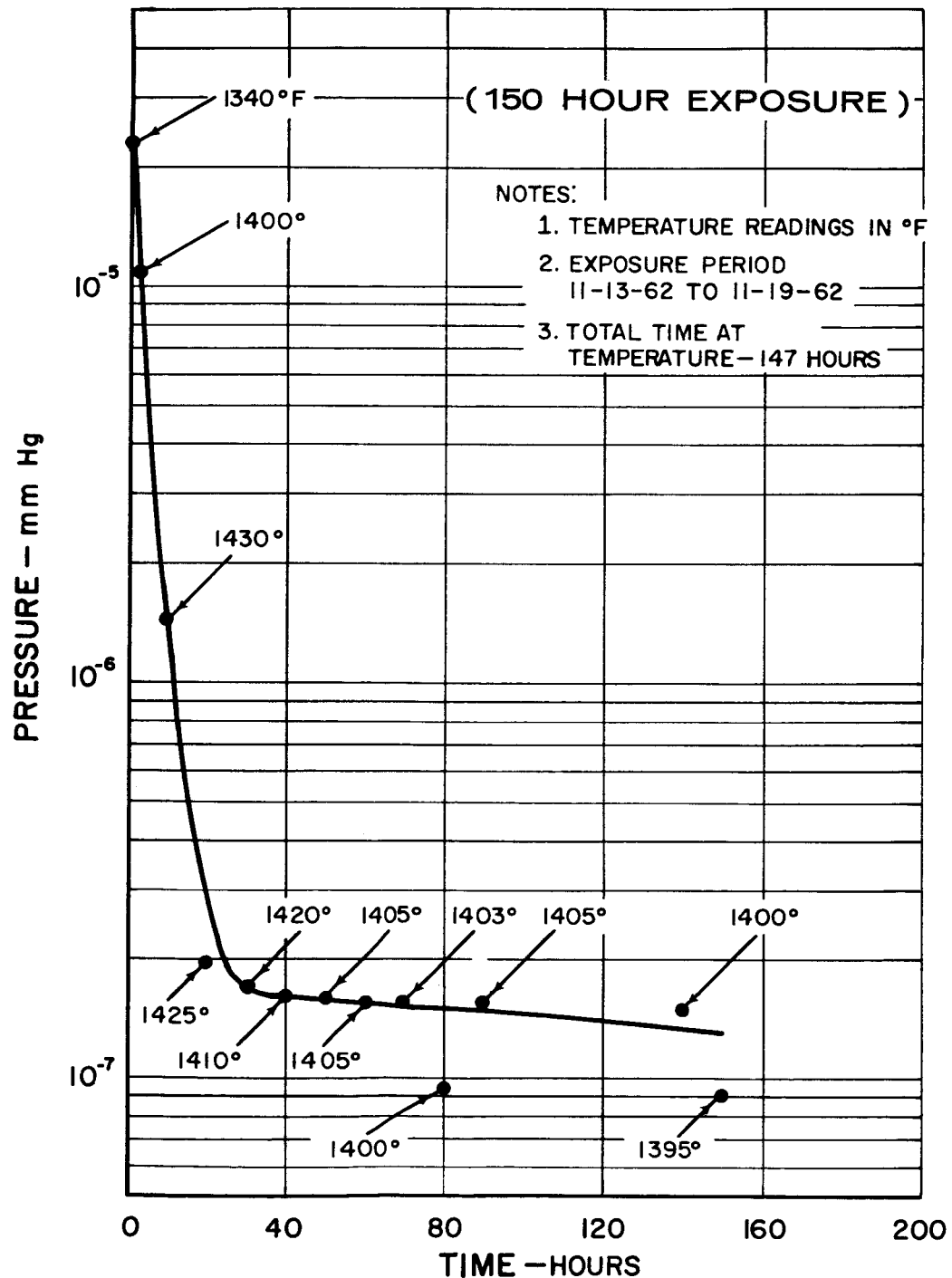


Figure 10

# ELEVATED TEMPERATURE EXPOSURE DATA FOR PLASMA SPRAYED CHROMIUM, IRON, AND TITANIUM COATINGS

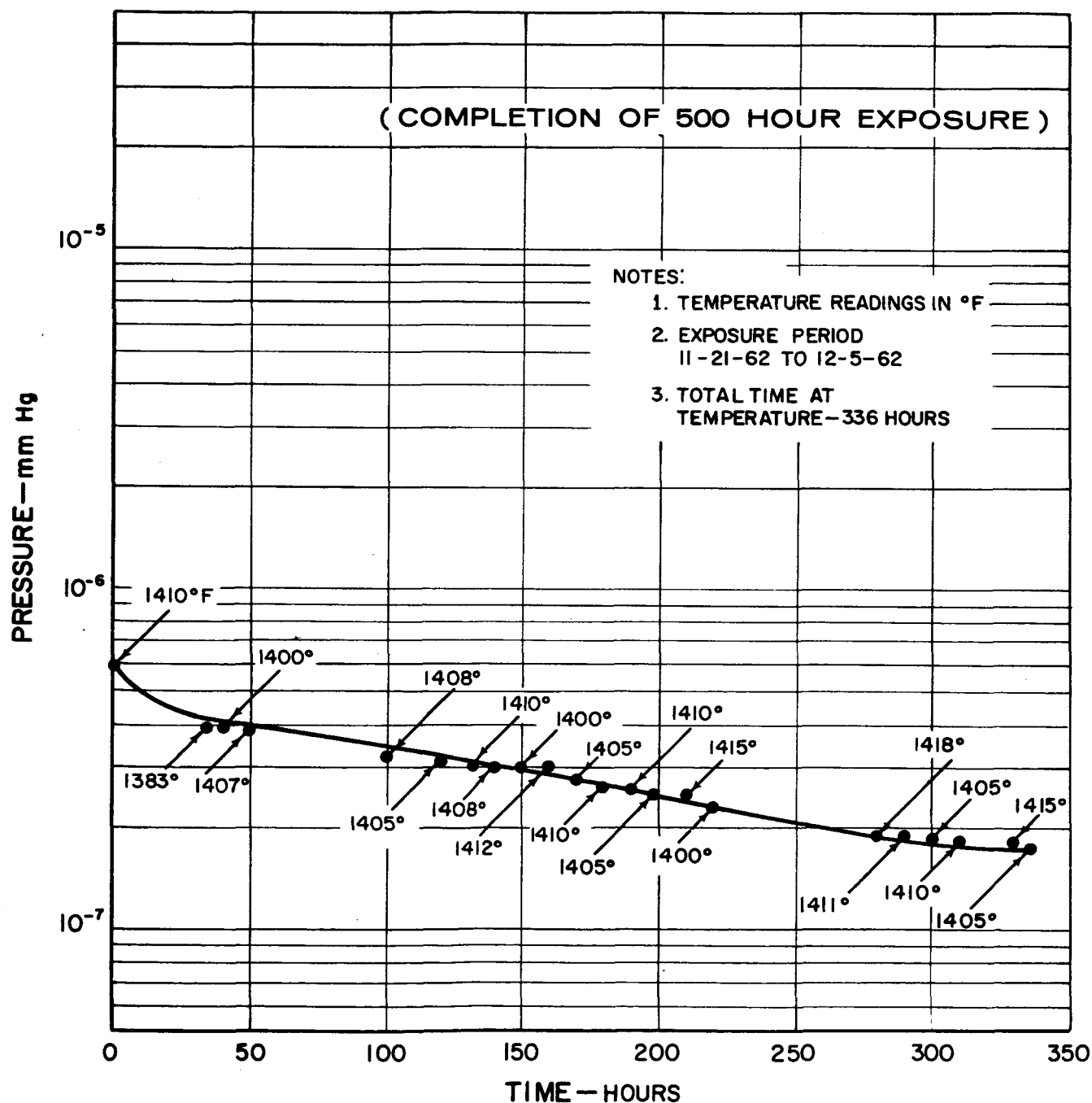


Figure 11

ELEVATED TEMPERATURE EXPOSURE DATA  
FOR PLASMA SPRAYED  
BERYLLIUM OXIDE COATINGS  
(150 HOUR EXPOSURE)

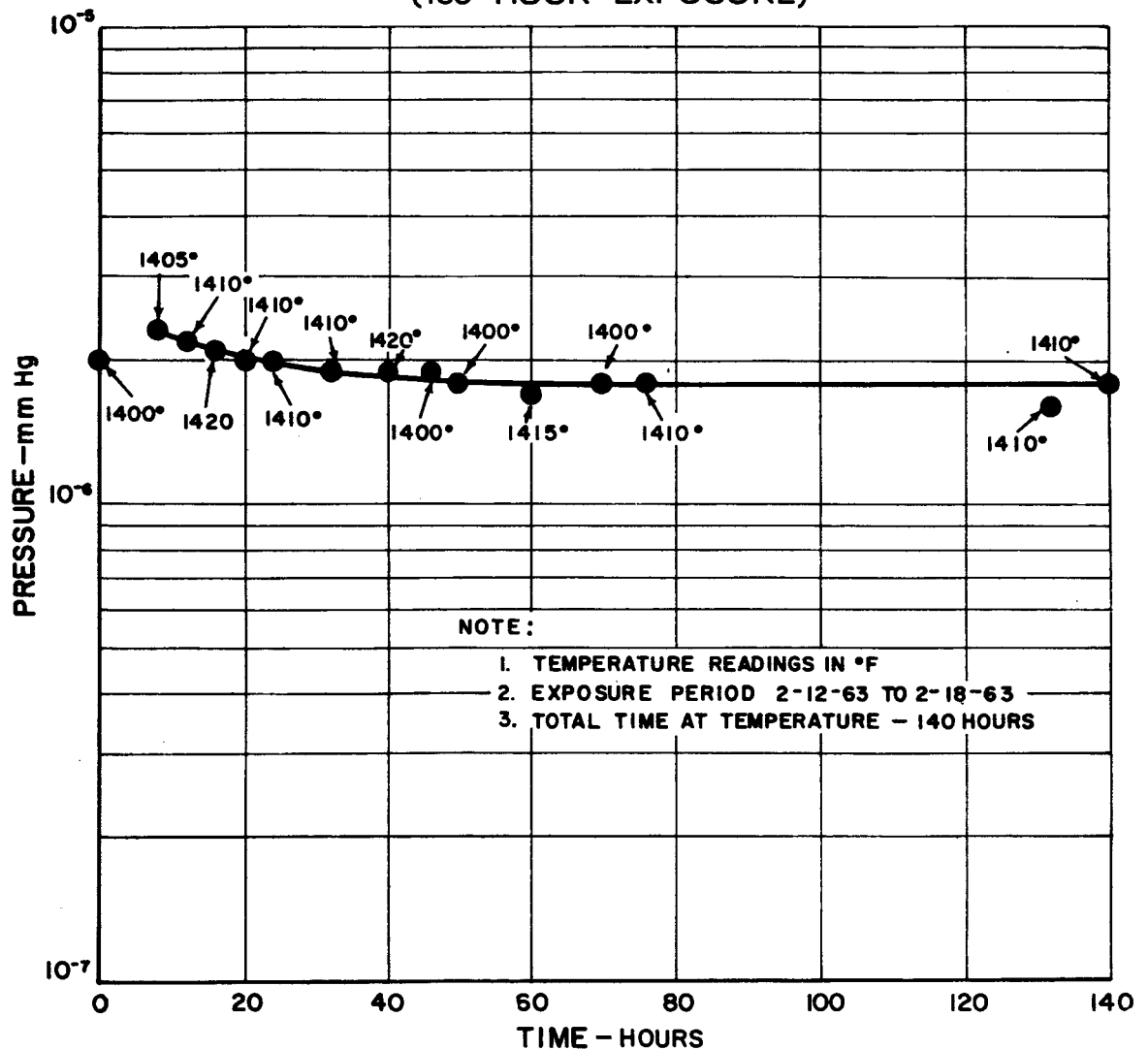


Figure 12

# ELEVATED TEMPERATURE EXPOSURE DATA FOR PLASMA-ARC SPRAYED BERYLLIUM OXIDE COATINGS

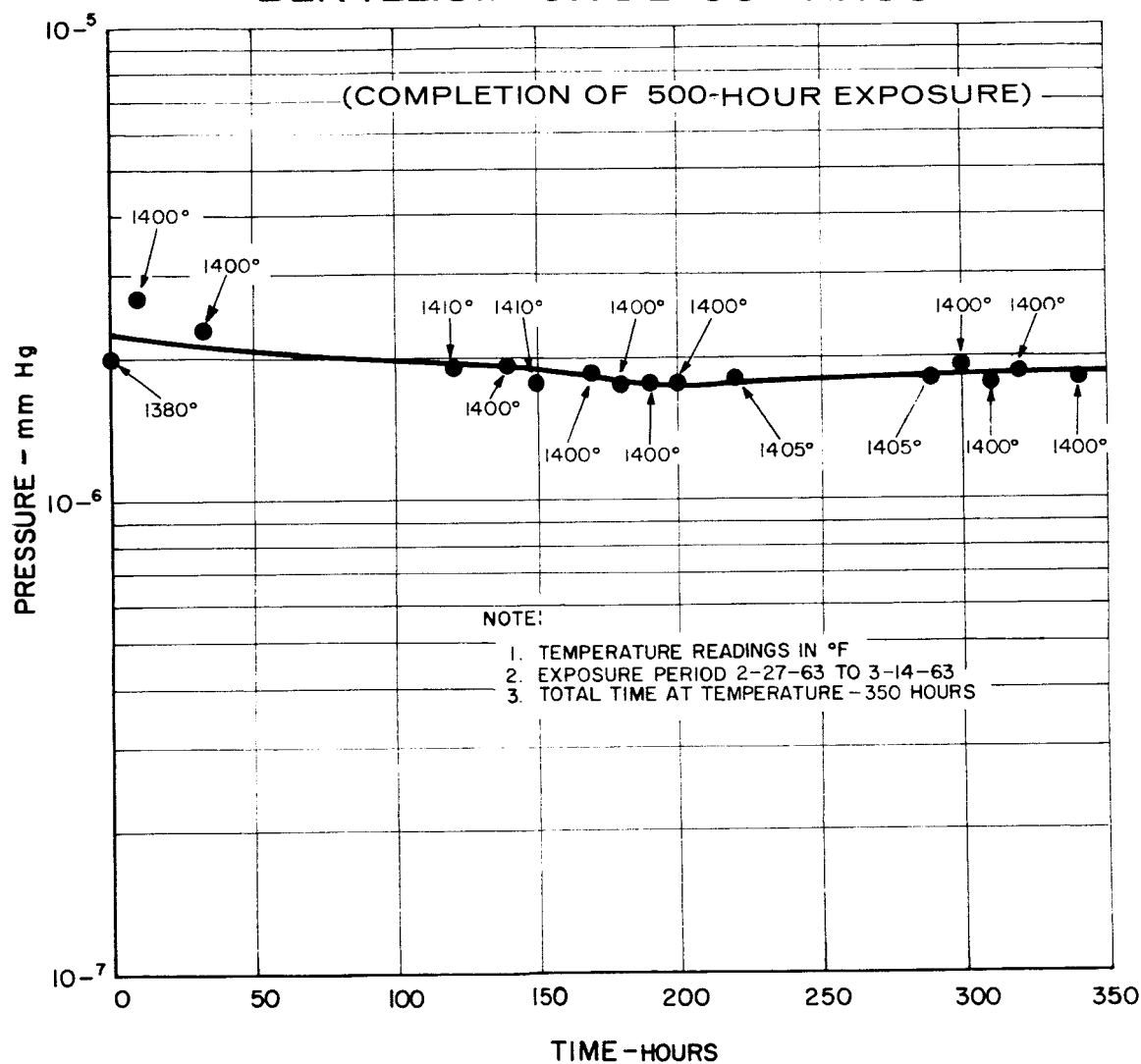


Figure 13

# ELEVATED TEMPERATURE EXPOSURE DATA FOR ELECTROPLATED GOLD COATINGS

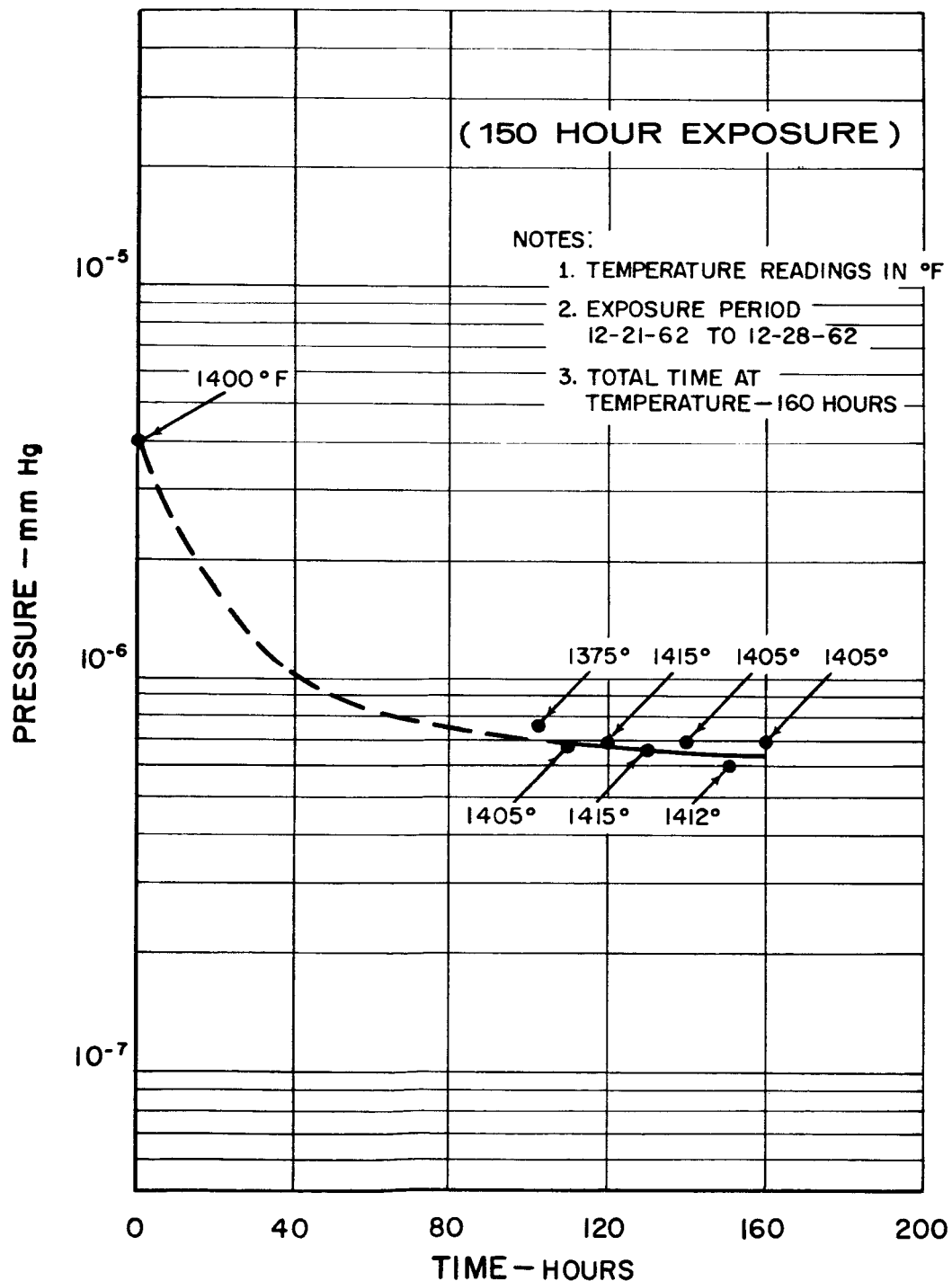


Figure 14

# ELEVATED TEMPERATURE EXPOSURE DATA FOR ELECTROPLATED GOLD COATINGS

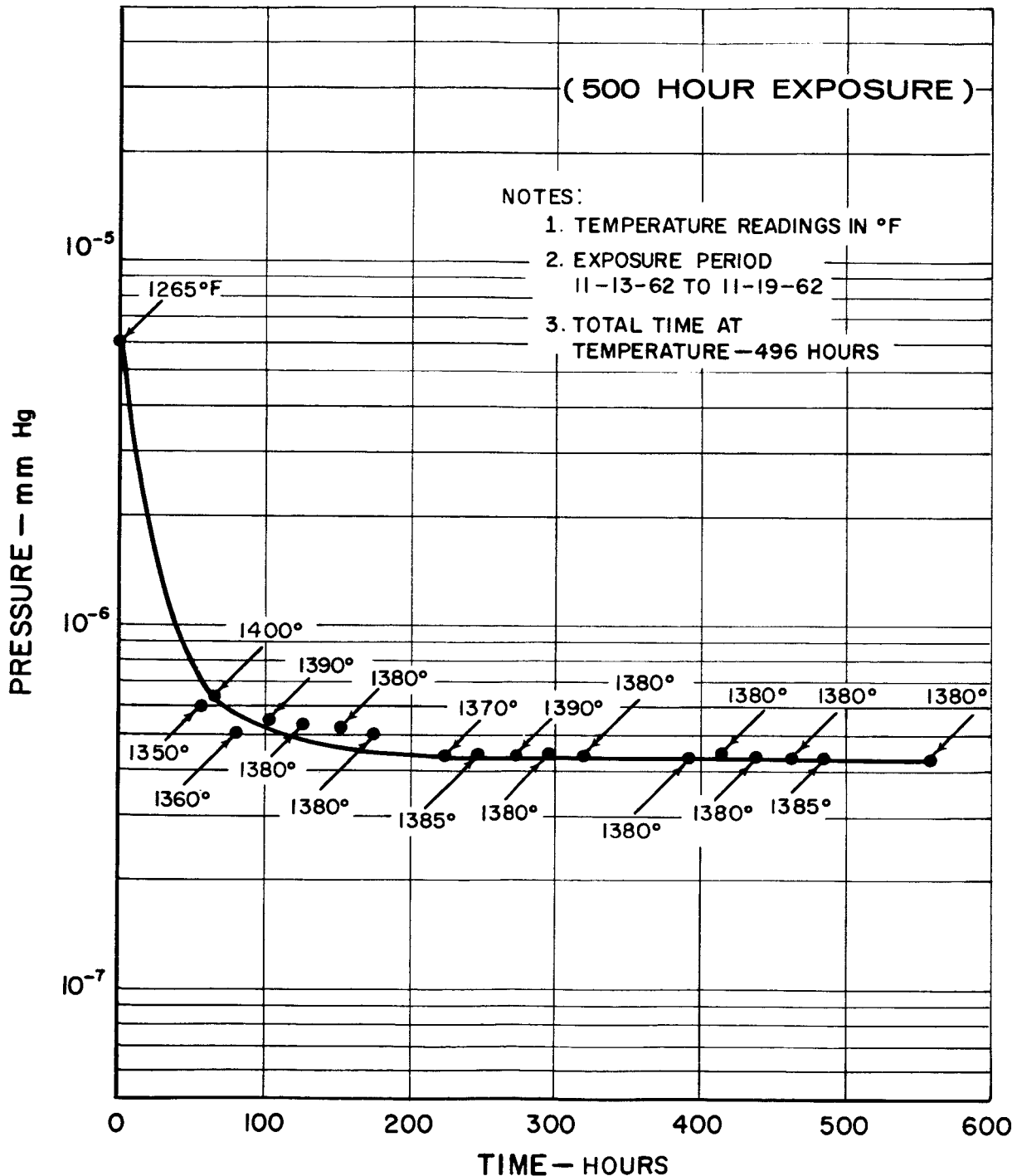
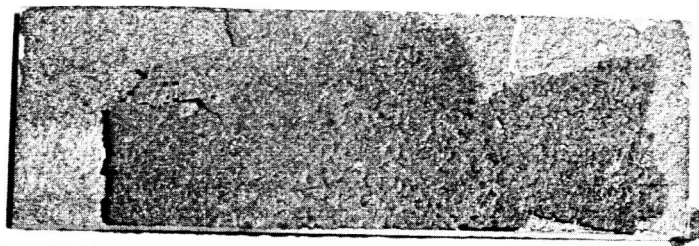
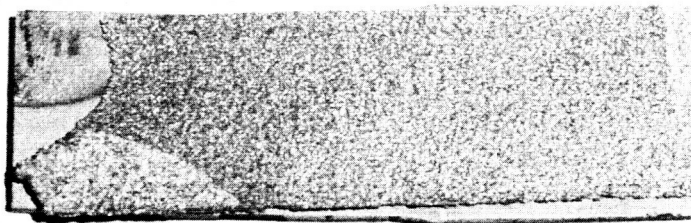


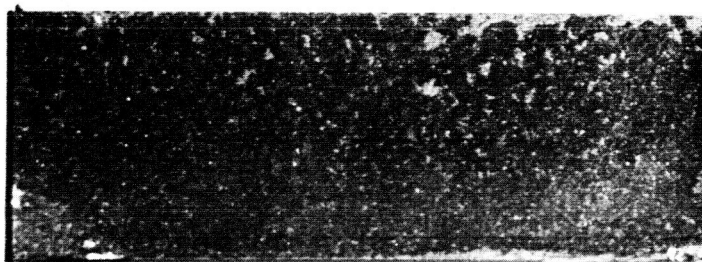
Figure 15



chromium



iron



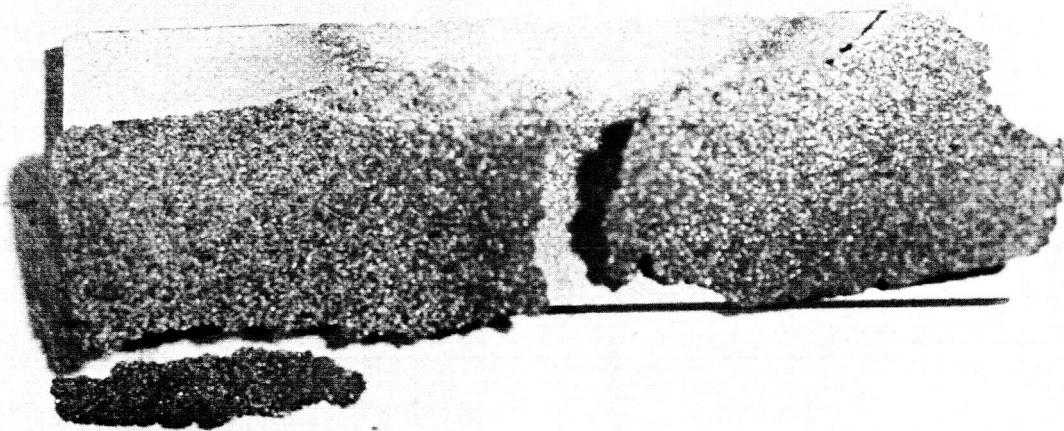
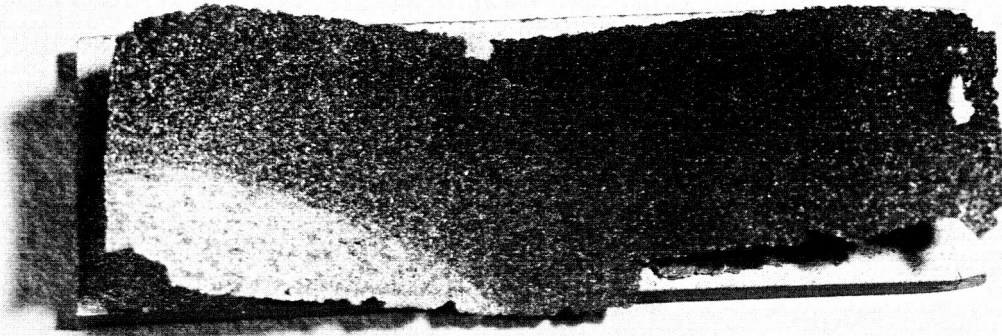
titanium



BERYLLIUM STRIPS PLASMA SPRAYED WITH CHROMIUM, IRON, AND  
TITANIUM AFTER 150HRS. OF EXPOSURE TO 1400°F

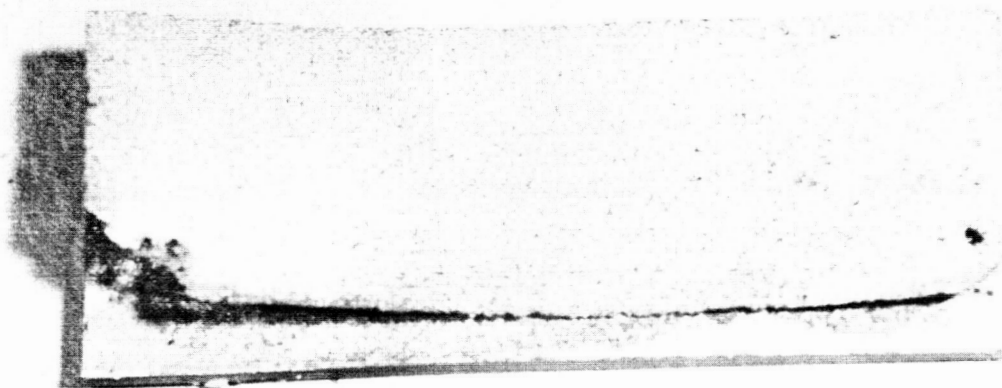
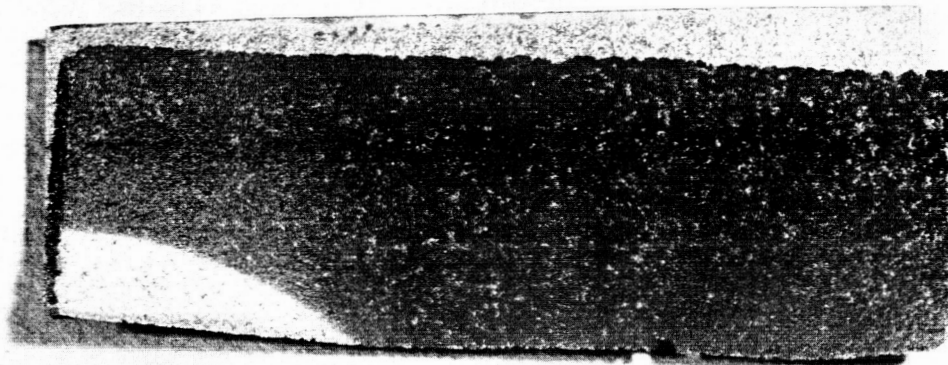
Figure 16





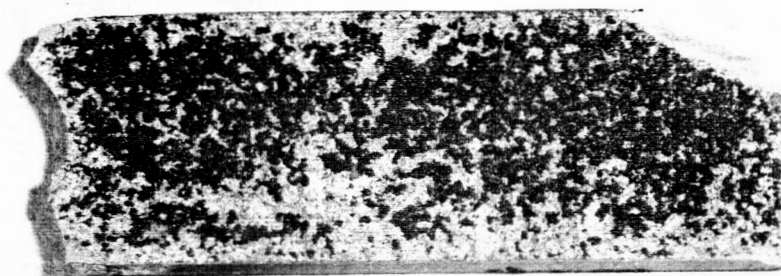
BERYLLIUM STRIPS PLASMA SPRAYED WITH CHROMIUM AFTER  
500 HRS. OF EXPOSURE TO 1400°F

Figure 17



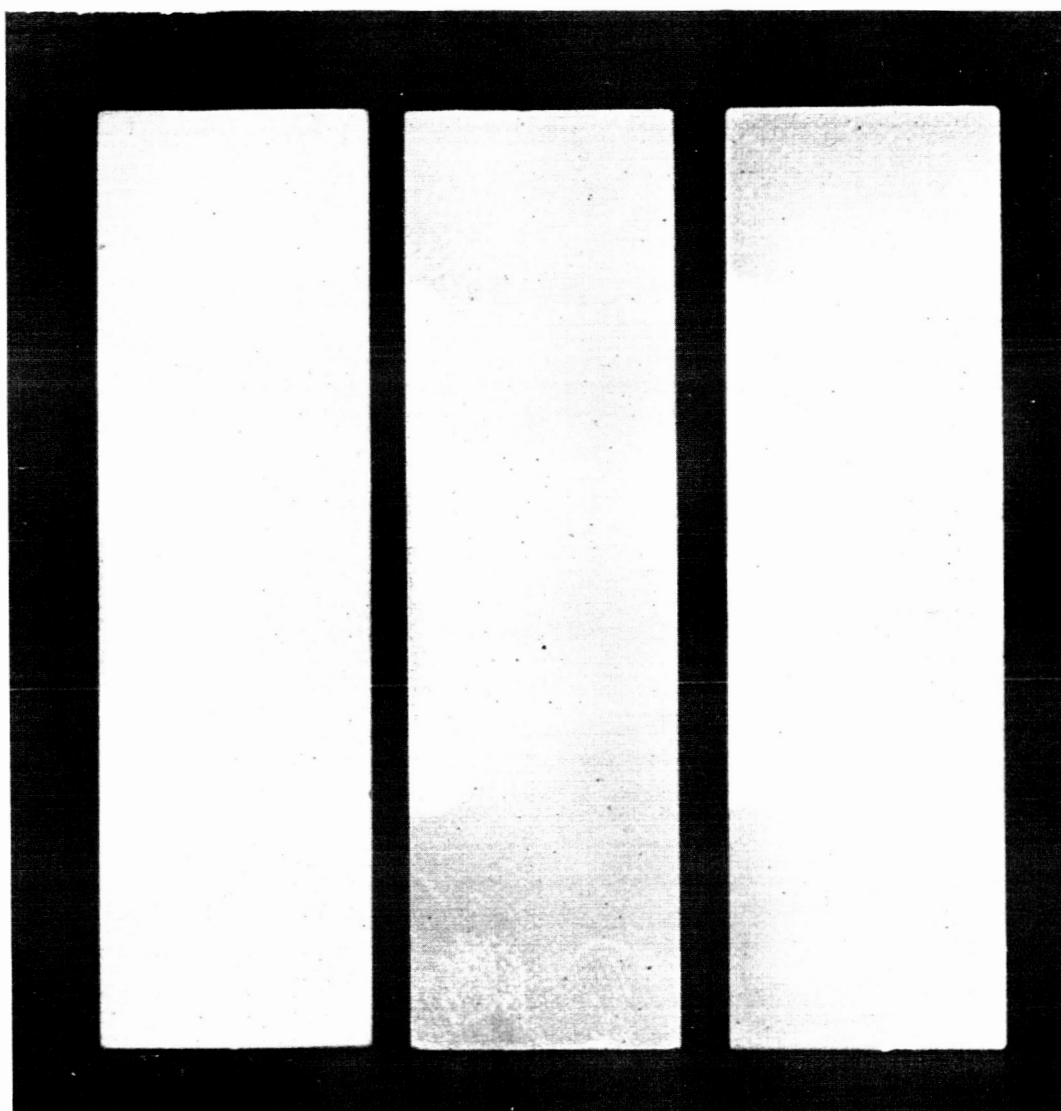
BERYLLIUM STRIPS PLASMA SPRAYED WITH IRON AFTER 500 HRS.  
OF EXPOSURE TO 1400°F

Figure 18



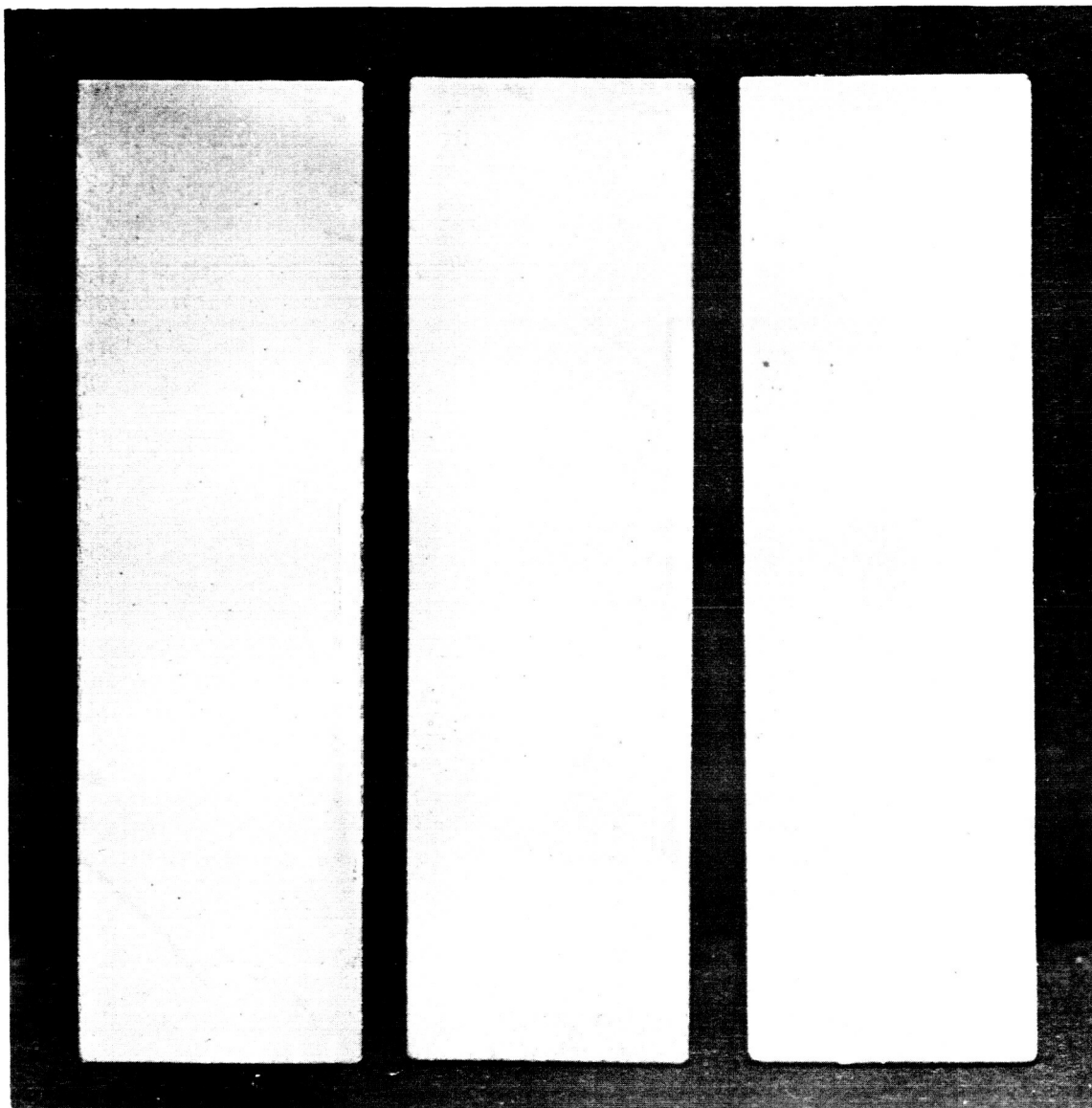
BERYLLIUM STRIPS PLASMA SPRAYED WITH TITANIUM AFTER  
500 HRS. OF EXPOSURE TO 1400°F

Figure 19



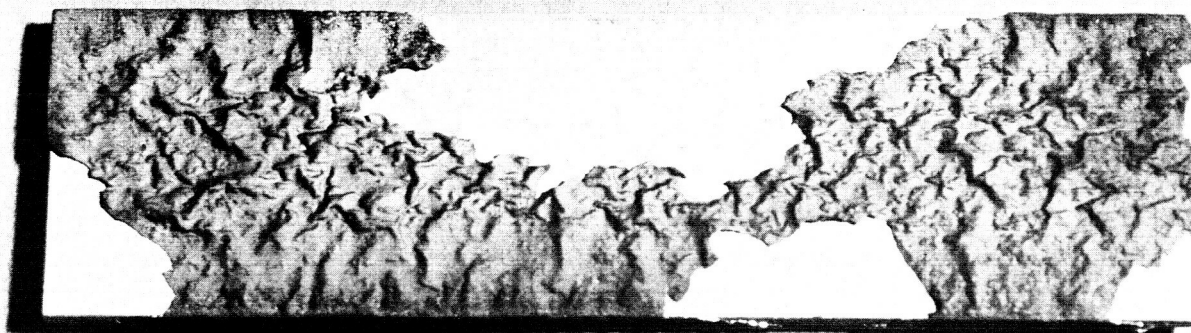
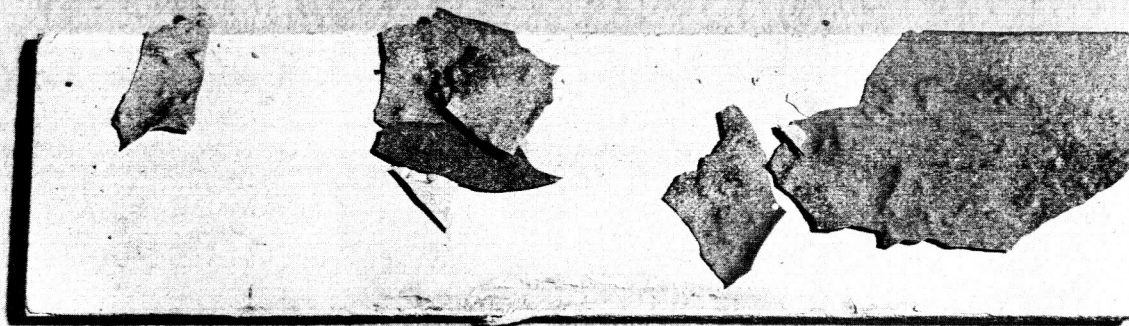
BERYLLIUM STRIPS PLASMA-ARC SPRAYED WITH BERYLLIUM  
OXIDE (1.0, 2.0, AND 3.0 MILS THICK) AFTER 150 HOURS  
OF EXPOSURE TO 1400°F

Figure 20



BERYLLIUM STRIPS PLASMA-SPRAYED WITH BERYLLIUM  
OXIDE (1.0, 2.0, AND 3.0 MILS THICK) AFTER 500 HOURS  
OF EXPOSURE TO 1400°F

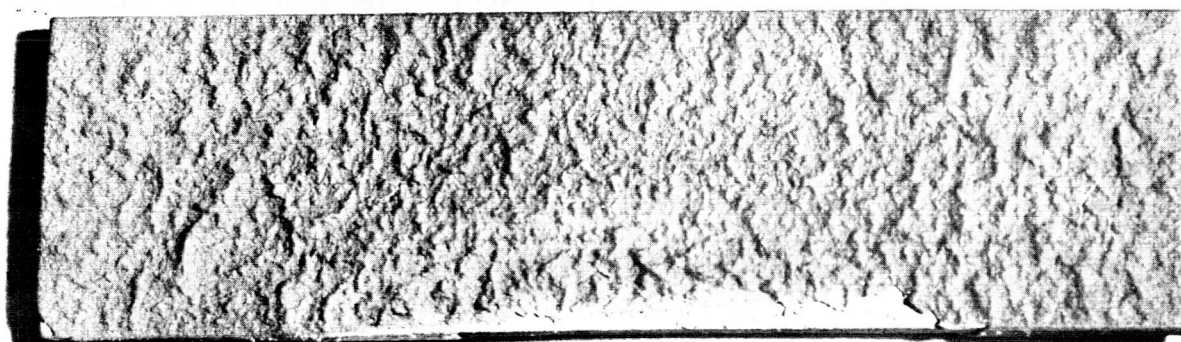
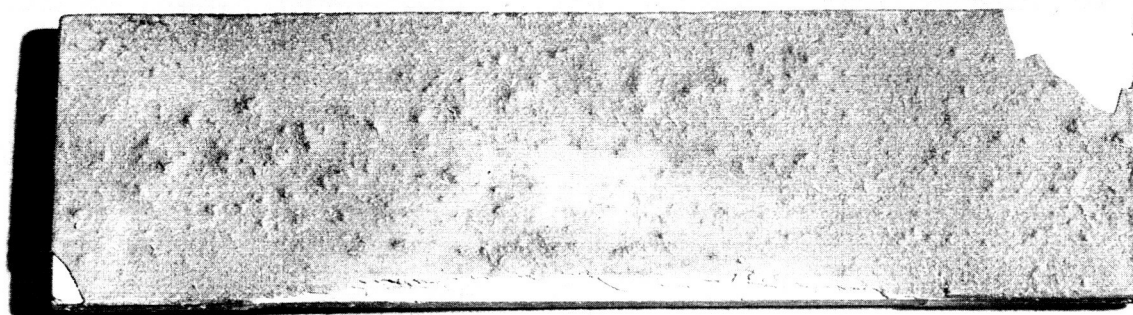
Figure 21



BERYLLIUM STRIPS ELECTROPLATED WITH A .75-MIL THICK  
GOLD COATING AFTER 150 HRS. OF EXPOSURE TO 1400°F

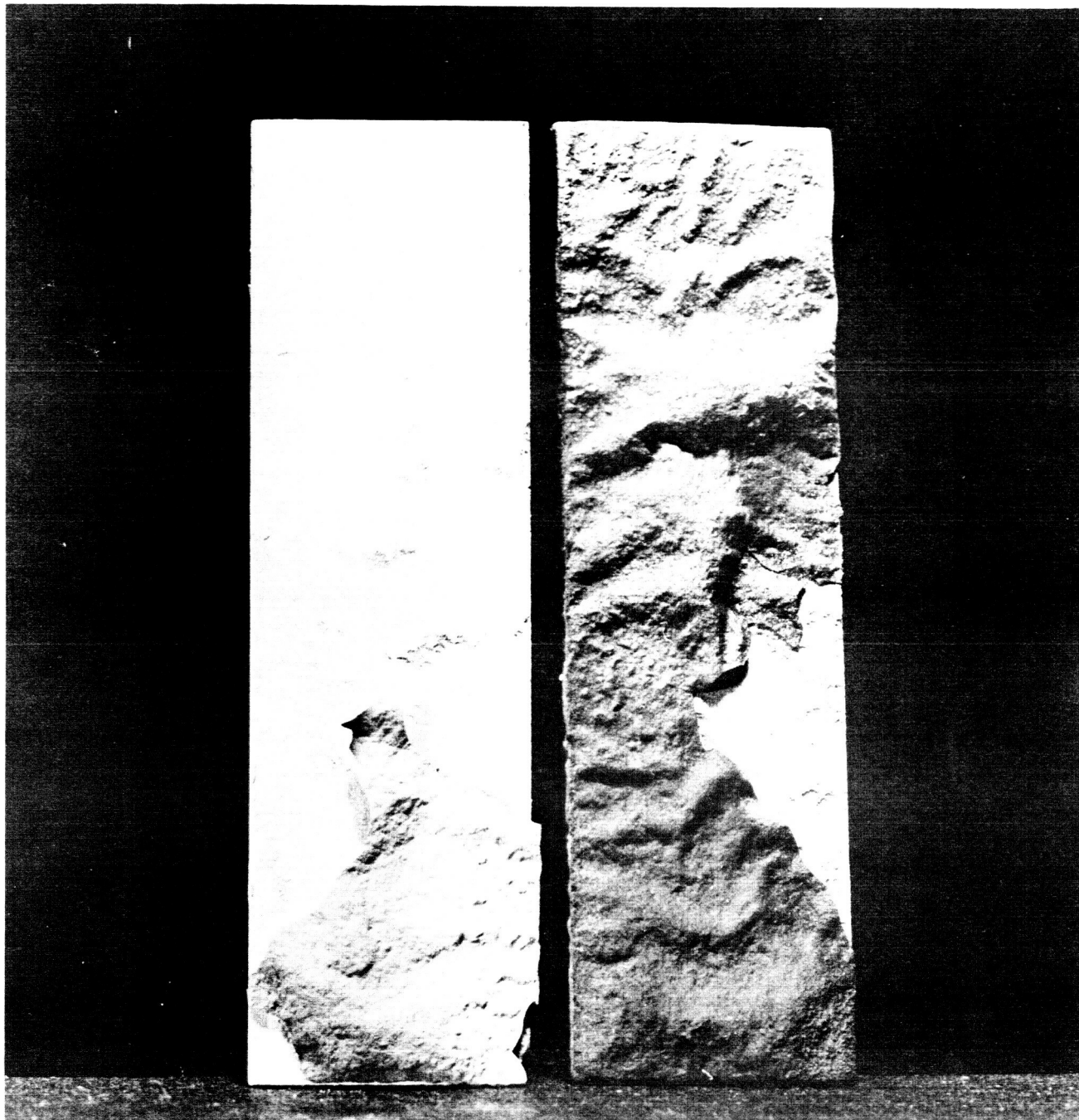
Figure 22





BERYLLIUM STRIPS ELECTROPLATED WITH A 1.5-MIL THICK  
GOLD COATING AFTER 150 HRS. OF EXPOSURE TO 1400°F

Figure 23



BERYLLIUM STRIPS ELECTROPLATED WITH A 1.5 - MIL THICK GOLD  
COATING AFTER 500 HRS. OF EXPOSURE TO 1400°F

Figure 24



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